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PATENT SPECIFICATION

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(54) BLOOD RESERVOIR

(71) We, JOHNSON & JOHNSON, a Corporation organised under the laws of the State of New Jersey, United States of America, of 501 George Street, New Brunswick, New Jersey, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to a blood reservoir, for use with apparatus and in methods for effecting heat or mass transfer across a membrane and has relevance to blood oxygenators and dialysers.

The transfer of mass or heat from one fluid to another, where the fluids are separated by a membrane, is the objective of many biological and industrial process. For example, an artificial lung, an artificial kidney and a blood heat-exchanger all use this principle. In an artificial lung, blood is separated from gaseous oxygen or another oxygen-rich fluid by a thin permeable membrane; the oxygen passes through the membrane into the blood, and carbon dioxide is released from the blood in the reverse direction. In an artificial kidney, the oxygen rich fluid is replaced by a dialysing fluid, and a wettable, permeable membrane particularly adapted for dialysis is used.

Since the development of the first membrane blood oxygenators and dialysers, membranes have been made progressively thinner and more effective. The resistance set up by blood flowing in channels or tubes has, however, been found to severely limit the rate of mass transfer across the membrane. Thus, the efficiency of these exchanges depends both on the permeability of the membrane which separates the two fluids, and on the ease with which the species being transferred (e.g. oxygen or carbon dioxide in the case of an oxygenator or artificial lung) is diffused within the fluids. Since oxygen is relatively insoluble in blood, it diffuses very slowly, and the efficiency of simple artificial lungs is very low. However, if the blood is well-mixed within the blood-channels, oxygen transfer can be greatly increased.

In our U.K. Patent Specification No. 1,442,754 there are described a method and apparatus for enhancing the mixing of blood and enhancing the rate of mass transfer across the membrane comprising forming the blood channels into furrowed surfaces, and pulsating the blood across these surfaces, so that eddies or vortices are generated within the hollows, thereby mixing the blood thoroughly and enhancing gas transfer.

More particularly, the apparatus for effecting heat or mass transfer between two fluids through a membrane described in Specification No. 1,442,754 comprises a conduit for flow of one fluid, said conduit being at least partly defined by said membrane and the configuration of said conduit in a plane orthogonal to the general direction of flow varying periodically along the general direction of flow either inherently or in response to fluid pressure therein in such a manner that when said fluid is pulsed along the line of the general direction of flow, a component of motion is induced therein which is mutually orthogonal to the surface of the membrane and the direction of flow.

Reference may be had to Specification No. 1,442,754 for a more detailed discussion of the conduit surface and other features of the apparatus and method disclosed therein.

It will be appreciated that when the fluid in the conduit is blood, flow must be non-

turbulent if trauma is to be avoided. In our Application No. 21183/75 (Serial No. 1,505,901) we described means by which an improved flow across the conduit disclosed in Specification No. 1,442,754 can be induced in blood, substantially without turbulence.

According to our Application No. 21183/75 (Serial No. 1,505,901) a method and apparatus are provided by means of which excellent transfer rates to or from blood may be achieved with the basic conduit structure disclosed in Specification No. 1,442,754 but employing pulsatile flow, of low amplitude fluctuation compared with the mean flow rate as produced by any pump producing a flow with small pulsations, referred to for convenience as a roller pump, which includes peristaltic pumps used in open heart surgery and vane-type pumps used in industrial processes. Thus we discovered that vortices can be generated by fluid passing over a surface with cavities in it, such as the surfaces described in Specification No. 1,442,754, under certain continual flow conditions which are produced by a roller pump as opposed to the reversing flow particularly described in Specification No. 1,442,754, and distinct from truly steady flow as achieved by gravity flow using a constant head tank. We define "low amplitude fluctuations" accordingly as fluctuations in which the flow is not reversed.

It is postulated that the vortices that occur in intermediate gently pulsating continual flow are effective in mixing blood because they are formed convectively (that is, by either continuous or rapidly alternating inflow and outflow processes). They form only when the flow speed is high enough to overcome viscous effects which tend to keep the boundary layer attached to the wavy wall of the conduit.

Vortex formation is observed in gently pulsating flow when the Reynolds number Up/v reaches about 200 (U being velocity of the fluid in the channel, v kinetic viscosity, and p hollow pitch—i.e. distance between ridges). For water in 1 mm depth semi-cylindrical hollows, the mean velocity has to exceed only about 3 cm/sec., but is preferably at least 10 cm/sec. to form convective vortices. No substantial turbulence is observed at mean velocities below about 50 cm/sec., but the mean velocity preferably should not exceed about 30 cm/sec., in order to ensure avoiding substantial turbulence. This 30 cm/sec. mean velocity upper limit corresponds to a Reynolds number, as defined above, of about 3000. The ratio of pitch to depth of hollow is at least 2 : 1, is generally below about 8 : 1, and is preferably in the range of 2 : 1 to 5 : 1, more preferably about 4 : 1.

In an oxygenator, it is necessary to have a large surface area and low resistance, which means, as a practical matter, average blood velocities too low for vortex formation with gently pulsating flow given the available blood supply from the patient—unless special means are provided to overcome this problem. In Application No. 21183/75 (Serial No. 1,505,901 we describe apparatus for adapting blood treating devices, such as artificial lungs embodying the conduit configuration taught in our Specification No. 1,442,754 for achieving eddy formations, to the use of gently pulsating flow, to thereby afford such additional advantages as the use of simpler, more readily available pumping equipment than would be required for creating reversing or violently pulsative flow. This apparatus comprises a blood reservoir, means for conducting blood from the patient to the reservoir, a roller pump for conducting blood from the reservoir through an oxygenator conduit (constructed as described in Specification No. 1,442,754) at a pulsatile flow, of low amplitude fluctuation compared with the mean flow rate, and at a mean flow rate which will achieve a Reynolds number between 200 and 3000, means for returning a portion of the oxygenated blood to the patient at a selected perfusion rate independent of the rate of flow of the blood through the oxygenator, and means for recycling a portion of the oxygenated blood to the reservoir. Preferably this apparatus includes means, conveniently associated with the blood reservoir, for introducing into the apparatus stored blood, blood components or other fluids, and for venting trapped air from the apparatus.

It is an object of the present invention to provide a blood reservoir particularly suited for use in the foregoing apparatus, this reservoir also acting as a mixing chamber for the blood.

According to the present invention the blood reservoir comprises a rigid lower housing, a flexible, bag-like upper portion sealed to the periphery of the lower housing, first and second inlet means, preferably in the lower housing, for introducing blood from the animal to be treated, and, respectively, from apparatus for effecting heat or mass transfer between said blood and another fluid, such as the oxygenator, into the reservoir, the respective inlet means being appropriately disposed or other means being provided, for mixing the blood in the reservoir, and outlet means for drawing the mixed blood from the reservoir, for conveyance to the oxygenator. Preferably, as illustrated in the drawings (Figures 5, 6 and 7), the inlet means are disposed tangentially to the

housing, so that the introduction of the blood therethrough serves to create a vortex in the chamber whereby efficient mixing with substantially no trauma to the blood is effected, the preferred inlet means thus serving as the mixing means as well.

In the accompanying drawings:

Figure 1 is a perspective view of apparatus suitable for the oxygenation of blood, with parts broken away;

Figure 2 is an enlarged fragmentary portion of Figure 1, in section;

Figure 3 is a fragmentary longitudinal section of a tubular membrane suitable for use as an alternative conduit to that illustrated in Figure 2;

Figure 4 is a schematic view of a complete circulating system suitable for use in accordance with the invention described in Application No. 21183/75, (Serial No. 1,505,901) with the apparatus shown in Figure 1;

Figure 5 is a front view, partly in section, through a blood reservoir of the present invention suitable for use in the circulating system illustrated in Figure 3;

Figure 6 is a section along lines 6—6 of Figure 5;

Figure 7 is a plan section along lines 7—7 of Figure 5; and

Figure 8 is graph of clearance time vs Reynolds number using disturbed flow.

Illustrative embodiments of the present invention will now be described in connection with the accompanying drawings.

Referring now to Figures 1 and 2, the apparatus comprises a stack (11) of plates (12) each of which consists of two generally laminar membranes (13) of silicone rubber separated by and supported on a rigid support plate (14) comprising a series of ridges (15). Furrows (16) are formed in the membrane (13), the bottoms of which furrows are spaced from the support plate (14), the space between furrows (16) and support plate (14) defining oxygen flow channels (17). The ratio of pitch to depth of the furrows in the illustrated embodiment is 4 : 1. Each plate is vertically spaced from its neighbours by pairs of spacing strips (18) sealed to the membrane near opposing edges and parallel thereto, thereby forming a membrane envelope between adjacent plates for blood flow at right angles to the flow of oxygen. The disposition of adjacent plates (12) is such that the ridges (15) in support plates (14) vertically correspond. Typically, the ridges are about 0.4 mm apart. Adjacent membranes are, if desired, sealed at their edges to provide further security against leakage of blood through any gap inadvertently present between the spacing strips (18) and membrane (13). The stack (11) is provided with an oxygen distribution chamber (19) which communicates with the channels (17). The stack also communicates through blood inlet and outlet ports (21, 22) with a suitable pump (not shown) such as a conventional roller pump, having sufficient capacity for providing the desired rate of flow through the stack.

The type of membrane to be used in this apparatus is discussed in detail in our abovementioned Specification No. 1,442,754.

Referring now to Figure 3, there is illustrated an alternative transfer membrane (23), of circular cross-section, forming a conduit (24) for flow of fluid therethrough. Conduit (24) has constrictions (25) along the length thereof which space zones, in the form of circumferential furrows (26), one from another. When fluid in the conduit is flowed along the length thereof in the direction shown by the arrows A and at steady flow rates, vortices are set up in the zones as shown. When the fluid is blood, and dialysing fluid or a gas comprising oxygen is passed over the outer surface of the membrane, dialysis or oxygenation can be effected.

Figure 4 is a schematic illustration of a suitable blood circulating system employing an oxygenator. Blood is drawn from animal 27 and transported through conduit 29 to a reservoir 31. Additional whole blood, blood components, or other desired additives may conveniently be added to reservoir 31 through a suitable port (not illustrated). Blood is pumped, at a constant but disturbed flow rate, from reservoir 31 through conduit 33 and oxygenator 37 by a first pump 35, suitably of the conventional roller type.

A portion of the oxygenated blood exiting oxygenator 37 is returned to the animal 27 through conduit 39 by the action of a second pump 41. Pump 41 may be of the same general construction as pump 35. The capacities of the two pumps are so adjusted that the flow rate through conduit 39 is a safe rate for perfusing blood into animal 27—usually the same rate at which the blood is being withdrawn from the animal and blood is pumped through the oxygenator 37 at a steady rate suitable to obtain the desired Reynolds number. The oxygenator 37 at a steady rate suitable to obtain the desired Reynolds number. The remainder of the oxygenated blood is returned via conduit 42 to reservoir 31, where it is mixed with the oxygen-poor blood from the animal. In other words, pump 41 runs at the desired perfusion rate for the animal, whereas pump 35 runs at a rate sufficient to

keep the Reynolds number in oxygenator 37 in excess of about 200.

An embodiment of a blood reservoir of the present invention, suitable for use in the above-described system, is illustrated in Figures 5—7. Reservoir 43 comprises a rigid lower housing 45 and a flexible bag-like upper portion 47, both portions suitably being made of blood compatible synthetic polymer. Two tangential inlets 49, 51 are provided in the lower, rigid housing 45 for introducing into the reservoir blood from the animal and the oxygenator, respectively. An outlet 53, preferably at the bottom of rigid portion 45, is adapted to be connected with tubing to the pump inlet. The tangential flow at the inlets facilitates mixing of blood in the reservoir, while minimizing trauma thereto. The location of the outlet at the bottom of the reservoir enhances this effect.

The upper portion 47 of the reservoir is adapted to expand and contract to accommodate different volumes of blood, since, as is known, contact with air is harmful to the blood. Accordingly, the blood level in the reservoir is conveniently above the top of the rigid portion 45. Alternatively, the flexible portion 47 may be adapted to collapse into the upper portion of the cavity defined by rigid portion 45 in the event that the blood level is below the top of portion 45. Preferably, suitable support means are provided for reservoir 43. As shown in Figure 5, these means comprise a metal frame 55 fixed to rigid portion 45 as at groove 57. Suitably, additional hanger means 59 may join frame 55 to flexible portion 47, for example, through rings 61. A port 63 is preferably provided in flexible portion 47 for introducing stored blood or other fluids or therapeutic agents therethrough. Port 63 may also serve as a vent for venting air from the system as during priming.

WHAT WE CLAIM IS:—

1. A blood reservoir suitable for use in the method and apparatus of Application No. 21183/75, (Serial No. 1,505,901), comprising a rigid lower housing, a flexible bag-like upper portion sealed to the periphery of the lower housing, first inlet means for introducing blood into said reservoir from an animal, second inlet means for introducing blood into said reservoir from apparatus for effecting heat or mass transfer between said blood and another fluid, and outlet means for discharging blood from said reservoir, the respective inlet means being appropriately disposed or other means being provided, for mixing said blood within said reservoir.

2. A blood reservoir according to Claim 1, wherein said lower rigid housing has a substantially circular cross-section, said first and second inlet means are associated with said rigid housing and for said mixing at least one of said inlet means is disposed tangentially to the housing.

3. A blood reservoir according to Claim 2, wherein said outlet means is located at the bottom of said rigid lower housing.

4. A blood reservoir according to Claim 1, 2 or 3, further comprising a port for the introduction of stored blood or therapeutic agents into said reservoir.

5. A blood reservoir according to Claim 4, wherein said port is associated with said upper flexible portion.

6. A blood reservoir according to any of Claims 1 to 5, further comprising support means associated with said lower housing for supporting said reservoir and means co-operating with said support means for independently supporting said upper flexible portion.

7. A blood reservoir substantially as described and shown in Figures 5, 6 and 7 of the accompanying drawings.

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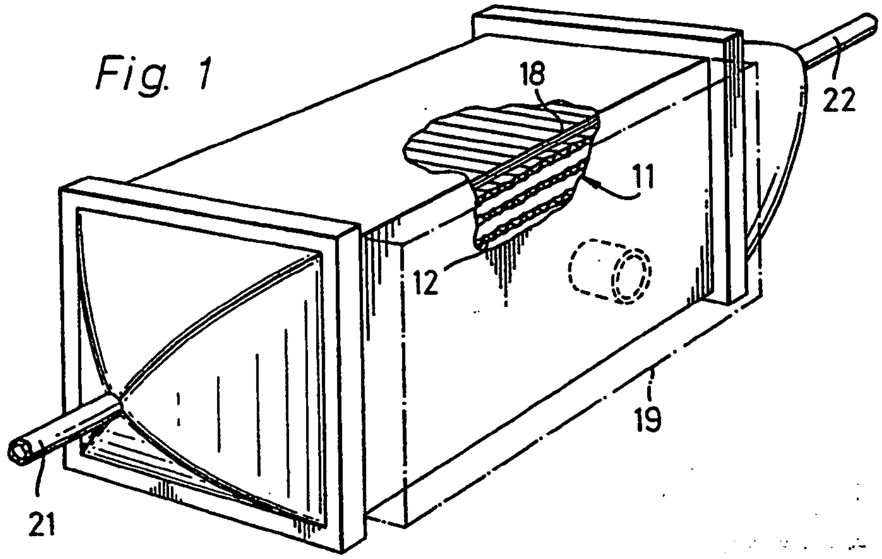
Fig. 1



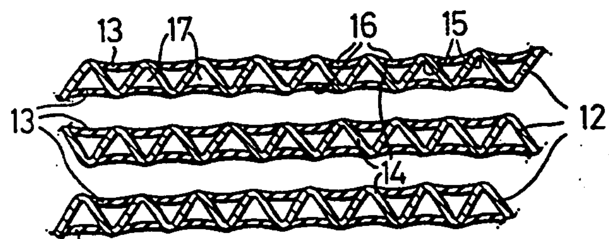


Fig. 2

Fig. 3

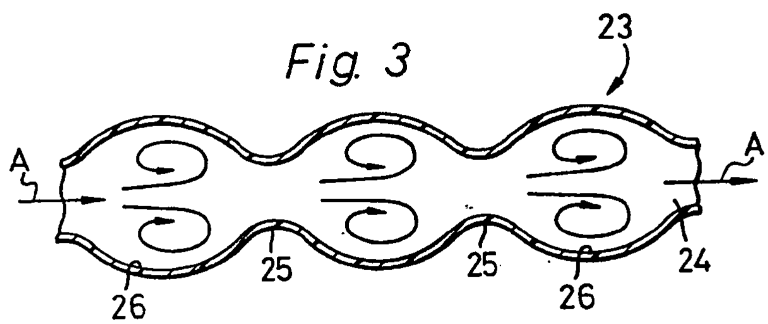
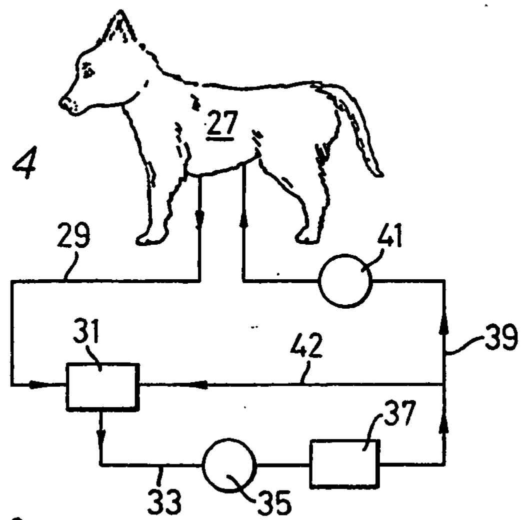


Fig. 4



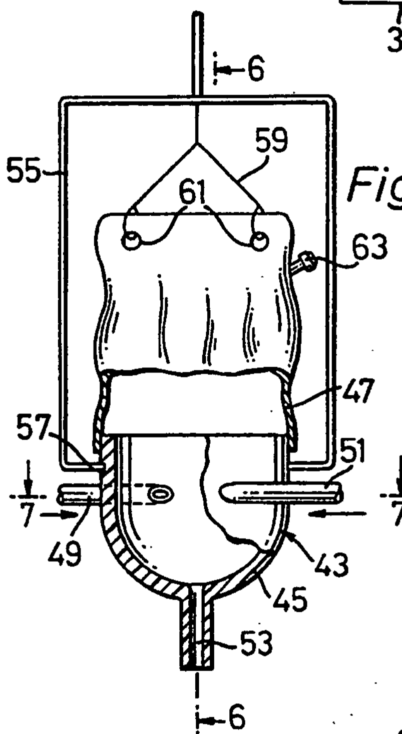
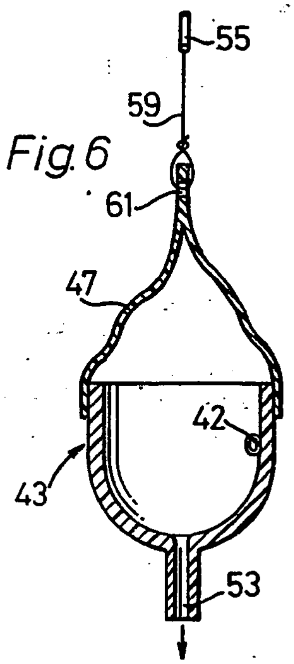


Fig. 5

Fig. 6



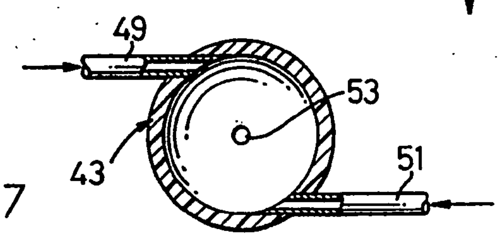


Fig. 7

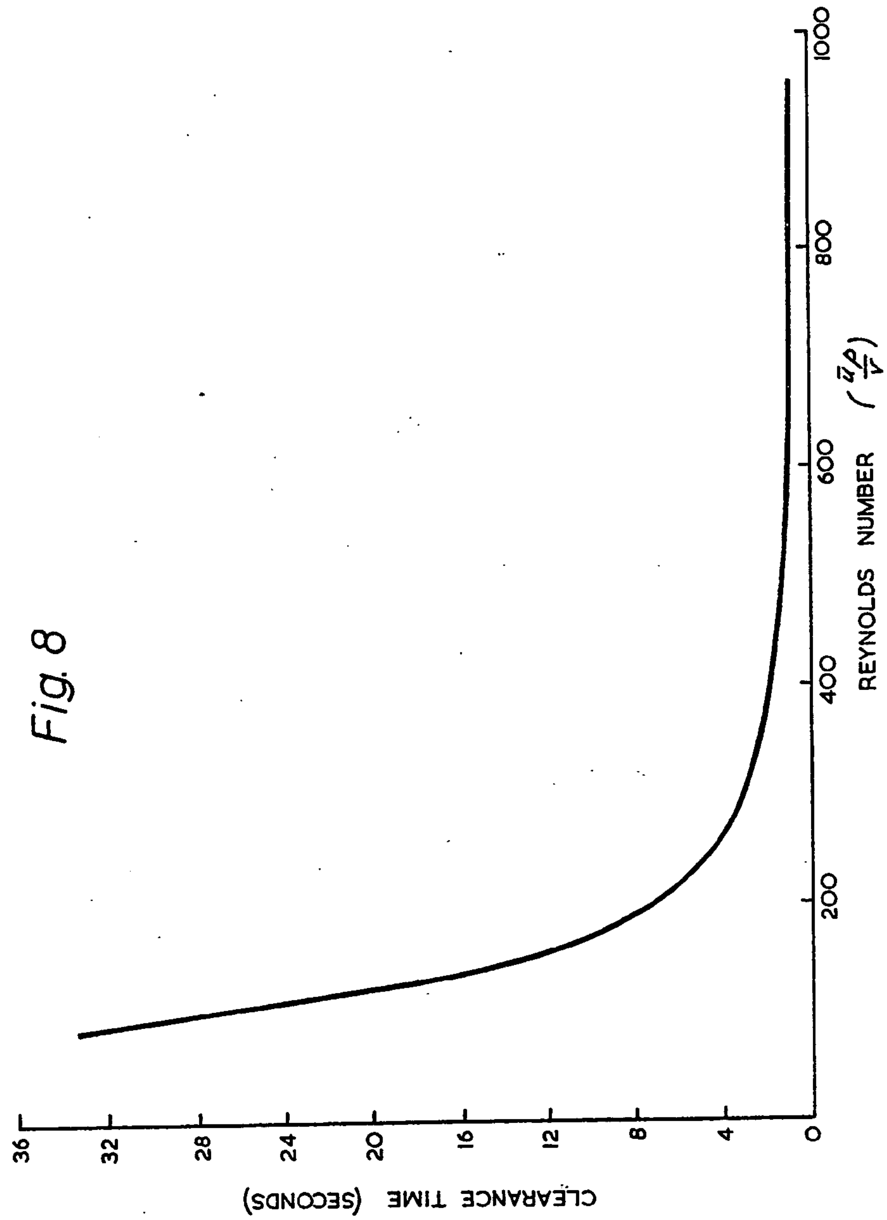

CLEARANCE TIME (SECONDS)
0
4
8
12
16
20
24
28
32
36
REYNOLDS NUMBER
200
400
600
800
1000

Fig. 8